A clinical study of caries diagnosis with a laser fluorescence system

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Tooth decay is a dynamic process resulting from an imbalance between demineralization and remineralization of the dental surface.[1] It begins when bacteria in acidogenic dental plaque—mainly *Streptococcus mutans, Streptococcus sobrinus* and *Lactobacillus acidophilus*—ferment carbohydrates in the diet,[2] producing organic acids such as lactic, formic, pyruvic, butyric, acetic and propionic acids. The acids' hydrogen ions act on hydroxylapatite crystals, freeing the calcium and phosphate mineral content and, thereby, initiating the process that forms a cavity.[1]

Once the diffuse destruction of the hydroxylapatite crystals has begun, the bacteria that invade the lesion in the enamel can reach the deepest layers of the enamel, even in incipient lesions without cavities, all the way to the amelodentinal limit.[3] This process is generally slow, and periods of demineralization alternate with other periods when, if oral conditions change, remineralization predominates.[4,5]

Preventive programs have decreased the prevalence and incidence of dental caries in children and adolescents[6-9] and have changed the pattern of caries distribution, with an increase in the proportion of occlusal caries.[7-12] In addition,

ABSTRACT

Background. The authors conducted an in vivo study to compare a laser fluorescence system with a visual system for occlusal caries diagnosis in children's primary and permanent molars.

Methods. The authors selected for evaluation 320 untreated, cavity-free primary and permanent molars in healthy children aged 6 through 14 years. Two of the authors conducted the laser fluorescence evaluation. Another of the authors completed the clinical evaluation. The κ value was 0.68. The authors compared sensitivity, specificity, predictive values, odds ratio and receiver operating characteristic (ROC) curves for the laser fluorescence system.

Results. For the whole sample, the sensitivity and specificity of the laser fluorescence system were 0.79 and 0.87, respectively. The positive and negative odds ratios for the whole sample were 6.33 and 0.23. The positive and negative predictive values for the whole sample were 33.9 percent and 98.1 percent. The value of the area beneath the ROC curve (AUC) was 0.92 for the whole sample.

Conclusions. The laser fluorescence system was more precise than visual evaluation in identifying lesions without cavities and healthy surfaces in primary and permanent molars.

Clinical Implications. In daily practice, dentists can consider the laser fluorescence system a complementary tool in the visual exploration of occlusal surfaces of primary molars and permanent first molars.

Key Words. Caries diagnosis; diagnostic tests; laser fluorescence system; early detection of caries.

JADA 2008;139(5):572-579.

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cavities appear later, and, therefore, occlusal surfaces that are clinically healthy and apparently intact may hide lesions that penetrate the dentin.

In children, the susceptibility to demineralization of primary teeth is greater than that of permanent teeth,[13] and the fact that the enamel in primary teeth is thinner means that the progression of decay is faster.[14] It is difficult to diagnose the depth of occlusal caries without cavities,[5,6,11,12,15-18] and the decision to restore the lesion or remineralize it varies greatly among dentists.[19-22] Thus, early detection and determination of the carious lesion's depth are fundamental because they can lead to a shift from surgical intervention to preventive treatment.[4,23-28]

The use of conventional diagnostic techniques seems satisfactory for the diagnosis of cavities[29,30] but inadequate for the diagnosis of lesions without cavities, lesions on the root surface or recurrent caries.[31] An ideal diagnostic method should offer a high level of sensitivity—that is, yield a low rate of false-negative findings. It also should be highly specific, yielding a low rate of false-positive findings. However, these properties are difficult to achieve using the traditional diagnostic methods that are based on visual exploration with a mirror, a probe, a halogen dental lamp and radiographs because they are subject to a broad variety of criteria among those performing the examinations.[22,32,33]

An ideal diagnostic method should offer high levels of sensitivity and specificity. However, these properties are difficult to achieve using traditional diagnostic methods.

Researchers and manufacturers have been developing instruments that measure the changes in dental tissue resulting from tooth decay by means of detecting the tissue's optical properties.[34] It is possible to contrast healthy enamel and carious tissue through an evaluation of the fluorescence stimulated by a laser or infrared light.[35] Red light, like infrared light, is absorbed less by enamel and is dispersed throughout the enamel to a greater degree than is light with a shorter wavelength. For that reason, infrared light penetrates more deeply, and it is possible to use infrared light to measure the fluorescence of dentinal caries located beneath the enamel even when the dental surface is clinically whole.[35]

Caries diagnosis is based fundamentally on a meticulous examination and the application of the clinical evidence of caries diagnosis. Nevertheless, many studies have demonstrated that the diagnosis of occlusal caries without cavities is difficult, and false-positive and false-negative findings occur frequently.[31,33,36-43] To avoid the occurrence of false-positive and false-negative findings, dentists may use complementary tools, such as a laser fluorescence system (for example, DIAGNOdent, KaVo Dental, Biberach, Germany).

Few studies have been performed that compare the results of clinical exploration with those obtained through the use of DIAGNOdent for diagnosis of children's primary and permanent molars. For this reason, we decided to study the validity of this instrument by measuring the fluorescence of occlusal surfaces in a sample of primary molars and to analyze the possible differences in the permanent molars of the same group of children.

METHODS, SUBJECTS AND MATERIALS

We performed our study within ongoing investigational activities of the Dental Care Program for Children–Pediatric Clinic of the Complutense University of Madrid (UCM), Spain, and it was approved by the institutional review board of the UCM General Foundation. We obtained consent forms from the children's parents or legal representatives on which they duly authorized the use of collected data for diagnosis.

We designed an in vivo study to use the DIAGNOdent fluorescent laser device (Model D88400) to measure the fluorescence of primary first and second molars and permanent first molars in a convenience sample of boys and girls aged 6 through 14 years who sought dental care at the pediatric clinic of UCM from January through October 2004.

The operation of DIAGNOdent is based on the concept of stimulation of fluorescence through the use of laser light. This device produces a red light with a wavelength of 695 nanometers that the user applies to the dental surface.[6,32,40,44] The light penetrates the enamel and the dentin, and the fluorescent light's intensity is measured by a photodiode and converted into digits, which appear

ABBREVIATION KEY. RSS: Research Support Service. **UCM:** Complutense University of Madrid.

Figure 1. Use of the fluorescent laser device on the occlusal surface of a primary first molar.

on a screen.

We used a linear scale, as proposed by the manufacturer, whose cutoff points were determined on the basis of previous studies[6,32,40,44] that relate histologic variations due to carious lesions with the measurement potential of the filtered light expressed in specific units for DIAGNOdent (KaVo Dental, written communication, Dec. 10, 2007). DIAGNOdent readings between zero and 4 indicate a healthy occlusal surface; readings between 5 and 25 indicate the presence of enamel caries, and readings of 26 or more indicate the presence of dentinal caries ($P \leq .05$) (KaVo Dental, written communication, Dec. 10, 2007).

We included in the study all the molars that had erupted completely; did not appear to have cavities, sealants or occlusal restorations; and did not have hypoplastic surfaces, pathological abrasions or other structural defects. We excluded from the sample molars of children who had systemic diseases that could interfere with the diagnostic process: temporomandibular joint defects that limited the child's ability to open his or her mouth and syndromes that made it impossible for the child to cooperate.

A single examiner (E.B.) who had broad experience in the clinical diagnosis of caries performed the visual exploration. She conducted it with a mirror, a no. 4 probe and a halogen dental lamp; she dried the occlusal surface beforehand for three to five seconds. The examiner classified the fissures according to the criteria established by Ekstrand and colleagues[39]: whole surfaces that do not require treatment, demineralized occlusal surfaces susceptible to remineralizing treatment or demineralized occlusal surfaces requiring restorative treatment.

Two examiners (M.M., M.A.) unfamiliar with the data obtained in the clinical exploration examined the same molars by using DIAGNOdent. Following the manufacturer's instructions, they dried teeth for two seconds and took readings in several places on the occlusal surface, noting the maximum value obtained. In accordance with the manufacturer's criteria, they classified surfaces as follows: values between zero and 4, healthy occlusal surface; values between 5 and 25, lesion limited to the enamel; values of 26 or more, lesion affecting the dentin (Figure 1). They used the same tip shape in all examinations to prevent reading variations (according to the technique suggested by KaVo Dental, written communication, Dec. 10, 2007).

The UCM Research Support Service (RSS) evaluated concordance between examiners through use of the κ statistic. RSS staff members calculated sensitivity, specificity, predictive values and the odds ratio of DIAGNOdent readings for the whole sample, as well as separately for primary molars and permanent molars. To determine DIAGNOdent's diagnostic precision, they traced a curve for the receiver operating characteristic (ROC). They established the level of significance at $P \leq .05$ for all cases, and they applied 95 percent confidence intervals (CIs). An analyst from the RSS performed the statistical data analysis by using a statistical software package (SPSS, Version 11.0, SPSS, Chicago).

RESULTS

After we applied the inclusion and exclusion criteria, the studied sample totaled 320 molars, including primary first (116) and second (127) molars and permanent first molars (77).

Results of clinical exploration. *Primary molars.* Of 243 occlusal surfaces, we diagnosed

200 (82 percent) as healthy, we classified 24 (10 percent) as susceptible to remineralization treatment and we determined that 19 (8 percent) required restorations.

Permanent molars. Of 77 occlusal surfaces, we diagnosed 49 (64 percent) as whole or healthy, 23 (30 percent) as needing remineralization treatment and 5 (6 percent) as needing restorations.

Of the whole sample of 320 primary and permanent molars, we diagnosed 249 (78 percent) occlusal surfaces as healthy, 47 (15 percent) as needing remineralization treatment and 24 (7 percent) as irreversible lesions requiring restorations (Table 1).

TABLE 1

Results of visual evaluation of primary and permanent molars, according to classification.

TYPE OF MOLAR	CLASSIFICATION, AS DETERMINED BY VISUAL EVALUATION* (n† [% F‡])			TOTAL (N)
	Healthy	Remineralization	Restoration	
Primary	200 (82)	24 (10)	19 (8)	243
Permanent	49 (64)	23 (30)	5 (6)	77
TOTAL	**249 (78)**	**47 (15)**	**24 (7)**	**320**

* The clinical visual evaluation was conducted by a single examiner who classified teeth according to criteria established by Ekstrand and colleagues.[39]
† N: Number in sample.
‡ F: Frequency.

Results of evaluation with DIAGNOdent. To measure concordance among the examiners, RSS staff members compared the results obtained by the two examiners through an evaluation of DIAGNOdent's data regarding molar surfaces, listed in Table 2 according to the whole sample, and separately for primary molars and permanent molars.

The concordance between examiners obtained through use of the κ statistic was 0.66 for primary molars, 0.71 for permanent molars and 0.68 for the total sample. Given that the concordance between the examiners was strong, we chose to use the data obtained by examiner no. 1 in the rest of the statistical analysis.

Sensitivity and specificity. DIAGNOdent's sensitivity for the diagnosis of unhealthy surfaces was 0.89 in primary molars and 0.40 in permanent first molars (Table 3). In the whole sample, this sensitivity index was 0.79.

The specificity obtained for diagnosing healthy surfaces was 0.89 for primary molars and 0.82 for permanent first molars. In the whole sample, the specificity was 0.87.

Odds ratio. We determined the ratio between the sensitivity and specificity values we obtained by calculating the negative and positive odds ratio. The positive odds ratio obtained was 8.36 in primary molars and 2.20 in permanent molars. The negative odds ratio was 0.11 in primary molars and 0.73 in permanent molars. The positive odds ratio for the whole sample was 6.33 and the negative odds ratio was 0.23.

Predictive values. The positive predictive value for DIAGNOdent's diagnostic test was 41.5 percent for primary molars and 13.3 percent for permanent first molars. The negative predictive value was 99.0 percent for primary molars and 95.2 percent for permanent molars. In the whole sample, the positive predictive value obtained was 33.9 percent, and the negative predictive value was 98.1 percent.

ROC curve. We analyzed the ROC curve for the purpose of relating the readings obtained by DIAGNOdent to the size of the caries, thereby determining the precision of occlusal caries diagnosis with DIAGNOdent (Figure 2, page 577). The value of the area under the ROC curve (AUC) obtained for the occlusal surfaces of primary first molars was 0.99 (95 percent CI: 0.99-1.00) (Figure 2A) and 0.90 (95 percent CI: 0.85-0.96) for the occlusal surfaces of primary second molars (Figure 2B). In permanent first molars, the value obtained was 0.72 (95 percent CI: 0.58-0.91) (Figure 2C). Finally, the AUC obtained for the whole sample was 0.92 (95 percent CI: 0.88-0.96) (Figure 2D).

DISCUSSION

A great discrepancy can exist among professionals when diagnosing occlusal caries without cavities[31,33,36-43]; therefore, clinicians' judgment is essential. Our study evaluated the clinical applicability of the DIAGNOdent laser device as a complementary tool in the visual exploration of the occlusal surfaces of primary molars and permanent first molars. This device was put on the market in 1998, and various studies, both in vivo[40,42,43,45-47] and in vitro,[48-51] have evaluated its reproducibility, sensitivity and specificity. The evaluation criteria we used were those defined previously by the manufacturer. In addition, sev-

TABLE 2

Results of laser fluorescence evaluation of primary and permanent molars, according to classification.

TYPE OF MOLAR	EXAMINER	CLASSIFICATION, AS DETERMINED BY LASER FLUORESCENCE EVALUATION* (n† [% F‡])			TOTAL (N)
		Healthy	Remineralization	Restoration	
Primary	1	114 (47)	88 (36)	41 (17)	243
	2	118 (49)	88 (36)	37 (15)	243
Permanent	1	18 (23)	44 (57)	15 (20)	77
	2	16 (21)	44 (57)	17 (22)	77
TOTAL	**1**	**132 (41)**	**132 (41)**	**56 (18)**	**320**
	2	**134 (42)**	**132 (41)**	**54 (17)**	**320**

* The laser fluorescence evaluation was conducted by two examiners who classified teeth according to criteria established by Ekstrand and colleagues.[39]
† N: Number in sample.
‡ F: Frequency.

TABLE 3

Laser fluorescence system's sensitivity and specificity in diagnosis of healthy surfaces.

TYPE OF TOOTH	SENSITIVITY	SPECIFICITY
Primary Molars	0.89	0.89
First	1	0.96
Second	0.87	0.82
Permanent First Molars	0.40	0.82
TOTAL	**0.79**	**0.87**

eral authors[42,43,52] have used the same criteria as those used in other in vitro studies.[41,48,49]

The criteria we adopted in this study to determine the validity of carious lesions were those published by Ekstrand and colleagues in 1998,[39] which classify the integrity of the occlusal surface according to its histologic validation. We considered clinical exploration essential for confirmation of the laser device's diagnosis, as did the various authors who also adopted this methodology in their studies.[36,40,41,43,53]

We found our results for the primary dentition interesting because few studies have been published that evaluated the use of the DIAGNOdent fluorescent laser device on primary molars. The only study comparable with our research was described by Rocha and colleagues.[42] The specificity we obtained (0.89) is lower than theirs (0.95), and the sensitivity we obtained (0.89) is higher than theirs (0.73). This may be because they considered values greater than 21 as signifying dentinal lesions,[42] whereas we considered readings of 26 or greater as signifying dentinal lesions.

Comparing the results obtained in this study with those of other authors, we observed that for permanent first molars, the sensitivity level of 0.40 we obtained is higher than the 0.17 obtained by Verdonschot and colleagues[4] but lower than the 0.92 obtained by Anttonen and colleagues[7] and the 0.81 reported by Angnes and colleagues.[45] Our study's lower sensitivity value for permanent first molars may be because we excluded lesions with cavities, thereby increasing the percentage of healthy teeth (64 percent) and caries limited to enamel (30 percent). Given that this diagnostic method is considered more sensitive for dentinal lesions,[54-56] it is reasonable that when lesions with cavities are excluded, a lower value would be obtained.

The difference in the number of false-positive findings we found between permanent and primary molars could be because that dentists find it easier to use visual exploration to diagnose occlusal caries in primary molars, given the characteristics of their occlusal morphology and their anterior location in the arch. We found no differences in sensitivity and specificity values between the groups of maxillary and mandibular molars, which is similar to the results obtained by Heinrich-Weltzien and colleagues.[40]

The positive odds ratio obtained for the whole sample (6.33) indicates a high capacity for discrimination in the diagnosis of carious lesions with the laser device. Nevertheless, it was much higher for primary molars (8.36) than for permanent molars (2.20).

The negative odds ratio obtained for the whole sample was 0.23 (0.11 for primary molars and 0.73 for permanent molars). These dissimilar negative odds ratio values point to a higher capacity for discrimination of caries-free surfaces in primary molars than in permanent molars.

The values we obtained for primary molars were similar to those published by Lussi and Francescut,[57] who used this device in a sample of 95 primary molars, and to the values published

by López and colleagues[55] for permanent first molars.

The values we obtained by analyzing the ROC curve in the molar groups we studied indicate that this diagnostic procedure was precise in all of the studied groups. Nevertheless, the AUC diminished from primary first molars (0.99) to primary second molars (0.90) and permanent molars (0.72). However, when comparing ROC curve values and the positive and negative odds ratios obtained for primary and permanent molars, we found a higher precision for primary molars. This could be due to histologic, morphological occlusal surfaces and eruptive chronology differences between primary and permanent molars.

The results obtained in this study by two different examiners for sensitivity and specificity values, odds ratios (positive and negative) and the ROC curve showed that the DIAGNOdent is a valuable complement to clinical examination. However, when we compared the results we obtained with the statistical tests for primary and permanent molars separately, we noted that DIAGNOdent demonstrated a higher precision and higher capacity to discriminate caries in primary molars than in permanent molars.

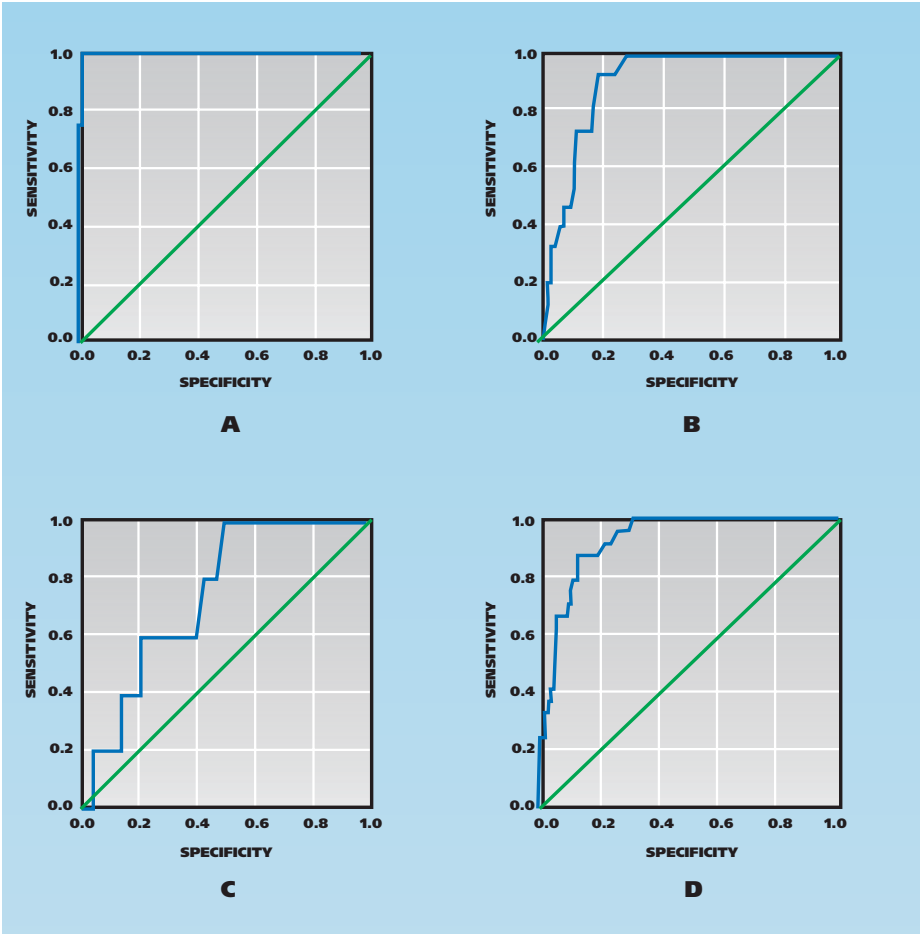

Figure 2. Receiver operating characteristic curves and areas under the curves. **A.** Primary first molars. **B.** Primary second molars. **C.** Permanent first molars. **D.** The whole sample.

The reproducibility of our study's data (κ = 0.68), confirmed by values obtained in previous research,[42,56-58] indicates that this laser device can be a tool for the longitudinal evaluation of occlusal carious lesions without cavities in patients who are at high risk of developing caries. The comparison of at least two consecutive measurements can alert the dentist to the existence of a lesion. In an in vitro study of primary molars, researchers demonstrated that the results obtained with DIAGNOdent by various examiners are more reproducible and homogeneous than those derived from visual exploration.[22] The results of our study affirmed that DIAGNOdent is accurate in diagnosing lesions that are undetectable with a probe. Given our results and the comparative analysis with results published by other researchers, we consider it important to include DIAGNOdent readings among the data necessary for making clinical judgments and therapeutic decisions.

CONCLUSIONS

The sensitivity we obtained in the exploration of occlusal surfaces using the DIAGNOdent fluorescent laser device made it possible to identify 89 percent of the lesions without cavities in the occlusal surfaces of primary molars. This complementary tool also revealed a high level of specificity for the same molars and locations, demonstrating the capacity to identify healthy surfaces in 89 percent of the cases.

The AUC we obtained for primary and permanent molars was close to 1.0. This makes it pos-

sible to state that the laser device is a highly precise diagnostic tool for the early diagnosis of occlusal caries in primary and permanent molars, as well as for the verification of the effectiveness of remineralization treatments in incipient lesions. ■

Disclosure. KaVo Dental S.A. (Biberach, Germany) donated the laser fluorescence system DIAGNOdent.

The authors thank the Research Support Service of the Complutense University of Madrid, Spain, for the assistance given on the statistical analysis.

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